Dependence of Plasma-Induced Oxide Charging Current on Al Antenna Geometry

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Abstract—**The dependence of the plasma-induced oxide charging current on Al electrode geometry has been studied. The stress current is collected only through the electrode surfaces not covered by the photoresist during plasma processes, and therefore is proportional to the edge length of the electrode during etching and proportional to the electrode area during photoresist ashing. Knowing the measured oxide charging currents, one should be able to predict the impact of these processes on oxide integrity and interface stability for a given antenna geometry more accurately.**

I. Introduction

GATE oxides in MOS devices can be degraded due to plasma processing. The damage was attributed to charge accumulation on the gate electrode during the plasma exposure [1]–[7]. Since this problem will become severe with device scaling down, a complete understanding of the damage mechanism is needed.

To predict the impact of these plasma processes on thin oxide integrity and SiO_2–Si interface stability for a given antenna geometry, we should determine which part of the antenna collects charges from plasma during each process. In this paper, we study the geometrical dependence of the stress current during plasma processing.

II. Experiment

The test structures used are MOS capacitors with 11.6-nm gate oxide. Aluminum etching was done in RIE system for 60 s at 60°C. The photoresist ashing was done in a barrel-type stripper for 60 min. Control wafers receiving only wet etching were also fabricated. Two types of test structures are studied. One consists of 1600-μm^2 capacitors with different Al pad sizes. The other group of capacitors have elongated aluminum "antennas" with the same area of 40 000 μm^2 but varying peripheral lengths.

By comparing the *CV* curve after plasma processing with the *CV*'s of wet-processed capacitors after constant current stress (Fig. 1), one can deduce the stress current (or the stress charge, which is the product of the stress current and the stress time) experienced by the oxide

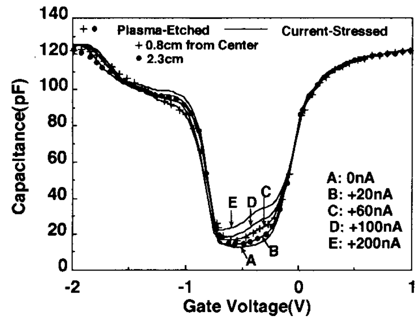

Fig. 1. *CV* of wet-etched 40 000-mm^2 capacitor after constant current stress for 60 s at varying current level (lines). The *CV* of the capacitor after plasma etching at 0.8 cm (cross) and 2.3 cm (circle) from wafer center match well with *CV* after 60- and 20-nA stress, respectively. This quantifies the oxide charging current.

during the processing. Even though most of the oxide stressing is believed to occur after the Al has been etched into individual patterns, the electrical current stress time was chosen to be the total etching time for simplicity and because the over etching time is not a constant over the wafer. Positive current was applied because the polarity of stressing during the etching was found to be positive for this etcher [9]. The electrical stress was done at room temperature for simplicity. If the electrical stress was carried out at the etching temperature, 60°C, there is only a minor shift in *CV*.

III. Results and Discussions

Fig. 2 shows the plasma stressing current during Al etching as a function of Al pad peripheral lengths. The slope of the line for the devices during normal aluminum etching is about 1. Clearly, the stressing current does not increase in proportion to the Al pad area. Rather, it is proportional to the peripheral length of Al pads. The implication is that only the Al surface exposed to the plasma can collect current. To support this conclusion, plasma etching was done with photoresist covering the entire surface of a wafer with Al pads previously patterned by wet etching. The magnitude of the oxide charging current is negligible compared with that for normal aluminum etching (Fig. 2). This confirms that the stress current is collected by the Al almost entirely through the edge of the Al pattern since the photoresist blocks the oxide charging current. Fig. 3 compares the oxide charging current for these devices with the stress current in

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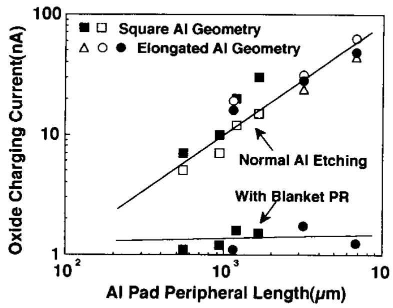

Fig. 2. The oxide charging current during the normal etching is approximately proportional to the Al edge length, independent of the Al pads shape and the oxide area. The oxide areas are 1600 and 40 000 μm^2 for square and elongated Al geometry, respectively. The areas of Al pads are 1600, 4800, 8000, and 16 000 μm^2 for square Al pads and 80 000 μm^2 for all elongated Al pads.

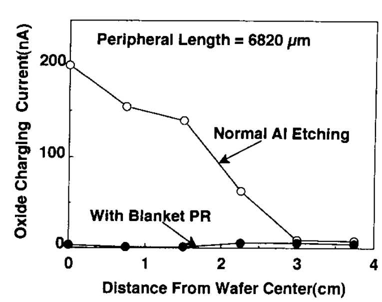

Fig. 3. Plasma oxide charging current for different locations during aluminum etching. The photoresist can block the charges from plasma.

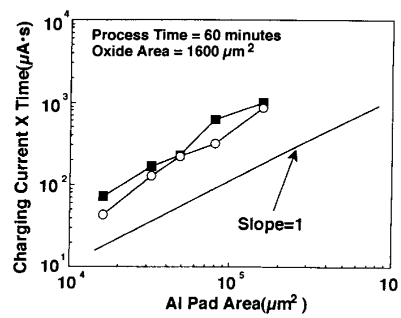

Fig. 4. Since the entire surface of the Al pad can collect charges from plasma, the oxide charging current during plasma photoresist stripping is proportional to electrode area. The two curves are for different locations on the wafer. The process time is 60 min.

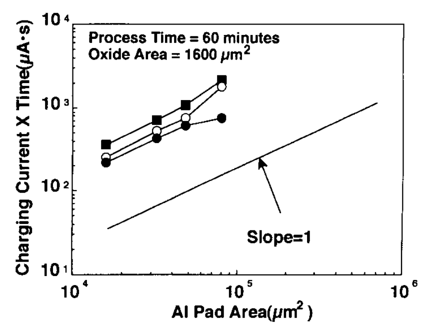

Fig. 5. The oxide charging current under plasma photoresist stripping condition without any resist present is also proportional to the Al pad area. The current is about four times larger than in the previous figure. Three sets of data taken from different positions are shown.

normal aluminum etching, during which the patterned photoresist covers the Al pads. There is a radial distribution of the oxide charging current across the wafer during normal Al etching due to the radial distribution of the plasma intensity and etch rate in this etcher. However, the small stress current detected with the Al patterns covered by a blanket photoresist layer is independent of the location of the device and is negligible. There was no detectable stress current in devices covered by blanket photoresist because there were no exposed Al surfaces.

Fig. 4 shows the stressing current–time product during plasma photoresist stripping as a function of aluminum pad *areas*. For this experiment, Al etching was done by a wet process to avoid plasma damage. The slope for all the lines is about 1. Clearly, the plasma stressing current is roughly proportional to the area of the Al pads. We interpret this as saying that most of the damage is done after the photoresist is stripped such that all of the Al pads are exposed. To support this interpretation, capacitors with bare Al pads previously patterned by wet etching were put through the photoresist stripping process even though the photoresist had already been removed by a wet process. The stressing current was also found to be proportional to the pad area (Fig. 5). This current is about four times larger than the value in Fig. 4. This is due to the fact that for the latter case the device collected the charges during the entire process whereas in the former case the stress current is collected only after the Al is exposed. The factor of 4 is roughly equal to the ratio of the total resist stripping time to the overstripping time.

IV. Summary

The geometrical dependence of the oxide charging current on Al geometry has been studied for Al etching and photoresist ashing. Since the photoresist can block the charges from plasma, the plasma stressing current is collected only through the exposed Al surfaces during the processes. The stress current is proportional to the Al pad peripheral length during etching, while it is proportional to the Al pad area during photoresist ashing. Knowledge of the geometrical dependence of stress current is critical for predicting the impact on oxide integrity for a given antenna geometry and establishing design rules accordingly.

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